

# A Study of Balanced 6G Architecture Combining Multiple Parameters

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*Abstract – Intelligent, autonomous, and immersive applications like Holographic Communication, Digital Twins, Autonomous Mobility, and Omnipresent Artificial Intelligence (AI) will be enabled by Sixth-Generation (6G) wireless communication systems. The current studies are mainly focused on performance-oriented parameters like ultra-reliable low-latency communication and extreme data rates. Research literature reveals that only considering these parameters is not sufficient for ensuring sustainability and social acceptability of 6G wireless communication systems. The necessity of daily exponential growth in terms of data harvesting, AI-based automation, and Telecom/IT network infrastructure densification have emerged as essential challenges for ensuring data privacy, incrementing energy consumption, and overdependence on autonomous decision-making. This paper presents a systematic analysis of various parameters of 6G architecture based on recent research studies in 5G, 5G-Advanced, Green AI, Edge-Cloud Intelligence, and Autonomous Control Systems.*

*This survey contends that the protection of privacy, the optimization of energy efficiency, and the development of autonomous systems are not isolated challenges, but are, in fact, closely related. In the event these challenges are viewed as standalone challenges, trade-offs and underlying tensions are apparent as soon as optimization occurs in isolation. By bringing together the findings of scholarly literature, industry analysis, and regulatory recommendations, the paper illustrates the importance of these challenges and how the failure to address one of these challenges may impact the scalability, trust, and sustainability of network systems. In light of the literature, the paper presents the concept of a unified architecture: integrating privacy-oriented data management, energy-efficient AI, and autonomous systems into the fundamental architecture of 6G networks. The major findings and their implications for future research illustrate the significance of the balanced and integrative architecture as the prerequisite for the development of strong, trustworthy, and sustainable 6G networks.*

**Keywords:** 6G Networks, Autonomous Networks, Green AI, Privacy Preservation, Energy Efficiency, Edge Intelligence

## 1. INTRODUCTION

The evolution of mobile networks has constantly been focused on providing a way to deliver increasingly sophisticated services, faster data, and quicker response times. The move from 4G to 5G has been a paradigm shift to a data- and service-centric approach, providing for Enhanced Mobile Broadband (eMBB), Ultra-Reliable Low-Latency Communication (URLLC), and Massive Machine-Type Communication (mMTC) services. However, as research into 5G evolution has shown, this is not sufficient for future intelligent and immersive experiences on its own [1].

Recent research indicates that 6G networks will not only improve telecommunication connectivity. Instead, it will be "AI-native, autonomous, and context-aware" and will support "Holographic Communications, Digital Twins, Extended Reality, Autonomous Mobility and Massive Collaborative Artificial Intelligence," among other things. Unlike previous network generations, 6G will "integrate intelligence into all layers of the network, merging communication, computation, sensing, and control into one entity." This ambitious goal holds the key to enormous performance and flexibility improvements, but it also poses major challenges to be overcome.

Current research findings indicate that a performance-based approach alone does not promise the sustainability and integrity of 6G networks. With the increasing adoption of Generative AI, AI Agents, and continuous learning in 5G-Advanced and future networks, concerns about the massive data gathering, reliance on centralized intelligence, and increasing computational requirements are also rising [2], [10]. Research findings suggest that centralized AI training and control increase the risks of privacy breaches, cyber-attack vulnerabilities, and potential single points of failure in the network [7], [12].

Energy efficiency is a major bottleneck for AI-driven telecom systems. In fact, the benefits achieved by AI-driven automation could be easily reversed by the increasing carbon footprint of AI-related operations, i.e., training, inference, and continuous optimization, if not addressed, as highlighted by Green AI research [3]. In fact, the research on Cloud-

Edge AI Platforms indicates that intelligent workload management and lightweight models could save a significant amount of energy, and thus there is a need for designing energy-efficient options. [4], [15].

Autonomous Network Control is another essential building block of 6G. AI-driven self-configuring, self-optimizing, and self-healing techniques have demonstrated measurable advantages in terms of efficiency and interference management in 5G networks [5], [13]. Overdependence on Autonomy without Transparency, Governance, and Explainability can raise concerns regarding Accountability, Regulatory Issues, and Ethics of Decision-Making [7], [8]. The industry and regulatory literature emphasize the importance of Responsible AI use to promote Digital Trust and Social Acceptance of future communication networks [8], [14].

While ample research has been carried out on privacy-preserving learning, green networking, and autonomous control, the current studies mainly focus on each of these issues separately. The surveys and empirical studies are carried out to optimize specific goals such as privacy in federated learning, minimisation of carbon footprints in Green AI, and autonomy in intelligent control systems independently, without considering the relationships between these goals [6], [11], [16], [17].

With this intent, this paper contributes a literature review analysis that investigates the relationship between Privacy, Energy Efficiency and Autonomy In the context of 6G architectures. Through a literature review amalgamation of research, white papers, and regulations, the paper identifies the importance of these aspects being considered from an architectural perspective as opposed to being treated as distinct design objectives. The paper hopes to identify some important observations and design insights that can be used to inform future research and development of 6G architectures.

## 2. BACKGROUND AND RELATED WORK

### 2.1 Evolution from 5G to 6G

The transition from Fifth-Generation (5G) to Sixth-Generation (6G) wireless communication systems marks a paradigm shift from connectivity-focused architectures to AI-native, intelligent, and autonomous systems. Although 5G has enabled the use of Enhanced Mobile Broadband (eMBB), Ultra-Reliable Low-Latency Communications (URLLC), and Massive Machine-Type Communications (mMTC), the intelligence in 5G is centralized and cloud-centric with less flexibility at the Edge Network [1], [2].

Recent works stress the importance of 6G in native intelligence integration among Devices, Edge Nodes, And Core Networks, which will enable proactive and Context-Aware Network Management [2], [7]. This closer convergence of communication and computation capabilities enables networks to predict traffic, environmental, and service changes rather than simply reacting to them. Figure 1 shows this progressive development, pointing out the growing intelligence and sustainability from 4G to 5G, 5G-Advanced, and finally 6G. Nevertheless, the literature also cautions that the pervasive use of intelligence enhances the complexity and management overhead. Learning in a distributed manner, model updates in real-time, and decision-making pose teething troubles in terms of energy, scalability, and management, as the intelligence is distributed in a assorted manner among various network components [3], [4]. Figure 1 shows the Line graph indicating the improvement in terms of “Intelligence” and “Sustainability” across the advancing technology of Telecommunication networks such as 4G, 5G, 6G etc, where the X Axis represents the Network Generation and Y – Axis represents the numerical scale quantifying the advances in terms of Network Smartness.

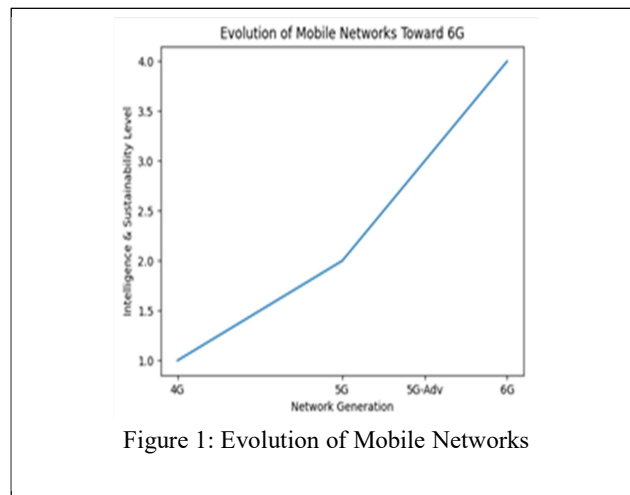


Figure 1: Evolution of Mobile Networks

## 2.2 Core Principles of 6G Architecture

From the literature surveyed, the 6G architectural vision is rooted in three fundamental principles: a) Privacy-first data management, b) Energy-efficient operation, and c) AI-driven autonomy. Initial 5G rollouts provided some foundation for these goals. Recent studies indicate that 6G needs to push for these to be the Foundation Pillars Of Design Principles [2], [3], [8].

From a privacy point of view, the current 5G networks are mostly based on centralized data aggregation and cloud-based AI training, which makes the sensitive user and network data vulnerable to privacy risks and regulatory issues [1], [2]. The 6G network architecture is expected to focus more on Federated Learning, Edge Intelligence, and Decentralized Data Processing to reduce the exchange of raw data and build user trust [2], [6], [15]. This is in line with the upcoming regulatory requirements for responsible AI systems [8].

Energy efficiency is the second essential tenet. The dense infrastructure and AI-intensive workloads that are typical of advanced 5G networks are responsible for high energy consumption and increasing carbon emissions [3], [4]. To address this, the 6G research community focuses on Green AI, energy-efficient models, and Smart Cloud-Edge Workload Management to enhance sustainability without sacrificing performance [3], [15].

Autonomy is the third fundamental tenet. Although 5G networks use Human-Assisted or Semi-Automated Optimization Techniques, 6G aims to be AI-native Self-Configuring, Self-Optimizing and Self-Healing Networks [5], [7]. Autonomy could lead to a substantial decrease in Operational Expenditure (OPEX) and latency, but it also requires explainable, auditable, and policy-aware control processes for reliability and accountability [7], [8].

These differences are summarized in Table 1, which compares the main architectural characteristics of 5G and 6G and their implications for trust, sustainability, and efficiency.

Table 1: Comparison of Key Parameters in 5G vs 6G

| DIMENSION                               | 5G                             | 6G                                 | IMPLICATION         |
|-----------------------------------------|--------------------------------|------------------------------------|---------------------|
| Privacy [1], [2], [6], [12], [15], [18] | Centralized Data Processing    | Federated & Edge Intelligence      | Improved user trust |
| Energy Efficiency [3], [4], [14], [15]  | High infrastructure energy use | Green AI & energy-aware design     | Sustainability      |
| Autonomy [5], [7], [13]                 | Human-assisted optimization    | AI-native self-optimizing networks | Reduced OPEX        |

## 2.3 Review of Existing Studies

This study observes that research on privacy preservation, energy efficiency, and autonomous networking has progressed largely along parallel but disconnected paths. Numerous studies address privacy-preserving learning techniques such as Federated Learning and Edge Inference [6], [15], while others focus on Green AI and energy-aware Network Optimization [3], [4]. Separately, autonomous control mechanisms leveraging AI and Open RAN architectures have been explored to improve network efficiency and adaptability [5], [7].

Very few works have chosen to investigate the relationships between these factors in a single architectural framework. Recent literature reviews have recognized the importance of holistic system design but have failed to provide a framework that can address all three factors simultaneously [2], [7]. Thus, there are solutions that fail to address the real-world issues where all three factors are interconnected.

This paper aims to address the research gap for a comprehensive system-level synthesis by examining the interaction of these three aspects and determining architectural trends that can support sustainable, trustworthy, and autonomous 6G networks.

## 3. RESEARCH METHODOLOGY

In this literary survey, a qualitative fusion method is used to analyse the new concepts of 6G that have been identified from the literature. Since 6G is still in the process of being conceptualized as a research paradigm, this method is useful in incorporating different perspectives into the study while maintaining a theoretical/ conceptual framework.

### 3.1 Data Collection

The data was collected through a systematic review of peer-reviewed research articles, industry white papers, and relevant international standards documents.

### 3.1.1 Academic Literature

The academic sources were obtained from trustworthy digital libraries such as IEEE Xplore, ACM Digital Library, Elsevier ScienceDirect, Researchgate, and MDPI. These Research Paper repositories offered access to theoretical models, empirical research, architectural analysis, and formal security models related to 5G and the latest 6G networks, as well as related domains like Artificial Intelligence and Cloud Computing.

### 3.1.2 Industry and Regulatory

Industry views were incorporated through reports from the World Economic Forum, and in relation to the regulatory environment such as the GDPR and the EU AI Act as well as telecommunications forums. This was done to ensure that the discussion is up-to-date with the realities of deployment and the considerations of the regulatory environment [9].

### 3.2 Inclusion and Exclusion Criteria

Only English-language technical publications were considered. Opinion-based Publications were excluded from analysis.

### 3.3 Thematic Analysis Procedure

A multi-stage thematic analysis was conducted, which included cross-domain mapping of AI-enabled systems in the telecommunications, finance, and media sectors.

#### 3.3.1 Cross-Domain Mapping

As a part of the cross-checking process, we also examined research that investigates the use of AI in Finance, Media, Entertainment, and Sports. These sectors rely heavily on IT-enabled, system-level processes that operate on telecom infrastructure and are now being increasingly supported by AI, Cloud, IoT, and Blockchain technology. By aligning these sectors together, we were able to identify common underlying principles while also recognizing the distinct patterns in each sector.

### 3.4 Reliability and Methodological Rigor

The analysis relied on several independent sources and a systematic cross-check of themes from academic papers, industry reports, and standards documents to increase the reliability of the results and reduce the risk of personal

bias. This increased the reliability and reproducibility of the results.

### 3.5 Methodological Limitations

As 6G has not yet standardized, this research is mostly based on secondary sources. The authors point to experimental validation as a region of future research.

## 4. CENTRALIZED 6G AI SYSTEMS

Centralized AI training consumes massive data collection raising critical privacy and energy issues. Centralized intelligence will enhance global optimization but will also introduce points of failure and increase the overall attack surface.

### 4.1 Data Privacy Challenges for AI Training Data in 6G Networks

6G will consume huge amounts of contextual, sensory, and behavioral data. With AI integrated into both the Edge and Core components of the network, the level of personalization and adaptability of services will be unparalleled. However, the AI increases the risk of privacy violations. In the current cloud-centric architecture, the training of AI models centrally involves aggregating sensitive user and network data.

To narrow down the impact of these challenges, solutions suggested include Federated Learning, Edge Inference, and Data Minimization/ Anonymization. However, these approaches introduce additional computation and coordination overheads. In the absence of a unified system-level approach, privacy-protection mechanisms may conflict with the need for low latency or energy efficiency.

Edge-Based Model Inference, Federated Learning and Decentralized Intelligence offer useful methods to boost privacy and reduce the need to transmit unprocessed data. These methods have setbacks, one of which is increased computation thereby energy consumption.

Figure 2 shows a comparison between centralized AI Training and Privacy-Preserving Edge Intelligence. It indicates that Edge Cloud Computing holds an advantage over the Centralized Computing Systems which carries a High Privacy Risk.

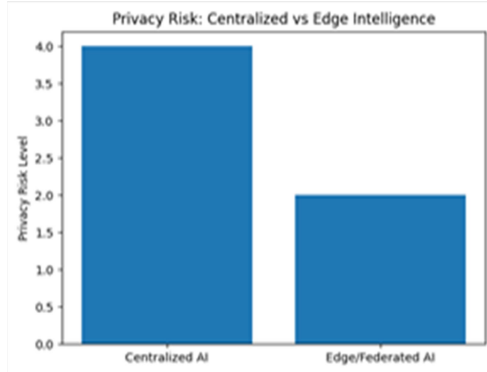


Figure 2: Centralized AI vs Privacy-Preserving Edge Intelligence

#### 4.2 Energy Efficiency and Sustainability for AI Compute Environment

Energy consumption is one of the major challenges for 6G networks, which is caused by the dense infrastructure, complex AI tasks, and the training and execution of models. Telecom systems powered by AI consume high amounts of energy due to massive model updates, extensive inferences, and very dense radio access networks.

Green AI studies indicate that the energy requirements of AI are expected to increase rapidly, with data centers and telecommunication networks being the major source of overall electricity consumption. Failure to adopt a systematic approach to efficiency will result in the power demand for AI-related applications to double by 2030. On the other hand, studies on cloud-edge configurations for AI indicate that optimized workload allocation and the use of light models can reduce energy consumption by more than 70% in controlled settings.

Energy-saving techniques in 5G, such as cloud-edge coordination, compact AI models, and sleep modes for network equipment, reduce carbon footprints. Unless properly coordinated, the objective of reducing energy consumption can conflict with autonomous control or low latency requirements. Figure 3 illustrates how these pieces fit together as AI intensity increases and energy consumption rises in telecommunication networks. These considerations underscore the importance of

energy efficiency as a core design principle in 6G, rather than an afterthought.

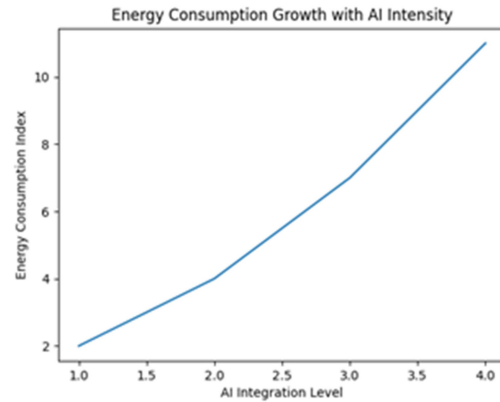


Figure 3: Energy Consumption vs AI Integration Level

#### 4.3 Autonomy and Intelligent Control

Autonomous networking is one of the cornerstones of 6G, and research on Open RAN control plane architectures and intelligent interference auto-optimization indicates that autonomy enabled by AI can significantly improve efficiency and quality. The adoption of Open RAN architectures and RAN Intelligent Controllers (RICs) introduces new security and governance complexities. The intelligence component could become a single point of failure or an attractive attack surface if it is not adequately protected.

Excessive autonomy, especially if it is not transparent enough, can amplify the risks of wrong decisions, security vulnerabilities, and non-compliance with regulations. Therefore, autonomous 6G network management requires methods that are explainable, energy-efficient, and privacy-respecting. Figure 4 illustrates the autonomous control loop for 6G networks. The diagram depicts the Closed Loop control is required for Autonomous Networks. The Continuous Loop feeds the all Network actions information back into the Data Stage to improve the AI analytical ability. This builds a self-learning dynamic system.

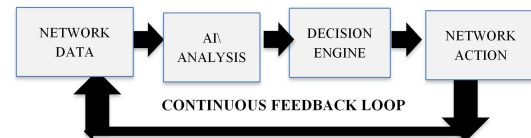


Figure 4: Autonomous Control Loop in 6G

## 5. CHALLENGES AND LIMITATIONS

The paper points out strong connections between privacy, energy efficiency, and autonomy as follows:

### 5.1 Privacy vs. Autonomy:

Autonomous AI systems require a lot of data to learn effectively, but collecting such data increases privacy risks for users.

### 5.2 Energy Efficiency vs. Autonomy:

On the other hand, automation using AI increases efficiency and productivity, but it also increases computational requirements and energy consumption.

### 5.3 Privacy vs. Energy Efficiency:

Computationally intensive privacy-preserving techniques such as federated learning and encryption introduce additional computational overhead.

As a result, it is necessary to optimize these factors together as part of a unified architectural vision. Edge intelligence is a key enabler in this regard, which enhances privacy, reduces backhaul energy consumption, and enables rapid, autonomous decision-making. The design of the 6G system must integrate Green AI principles into the fabric from the initiation.

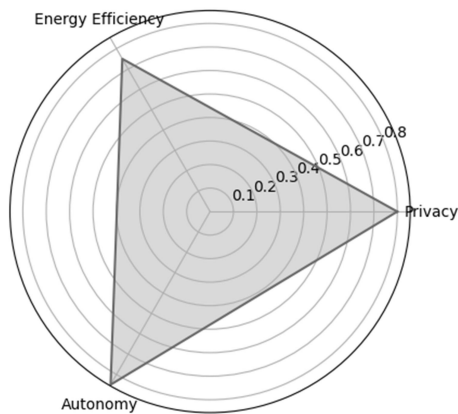


Figure 5: Interdependence of Energy Efficiency, Autonomy and Privacy

## 6. ANALYSIS

### 6.1 Findings and Observations

After analysing the different papers, the following are the most important points that I have gathered:

- i) 6G design must incorporate Performance, Sustainability and Trust, all integrated into the system [1], [3].
- ii) Privacy, energy efficiency, and autonomy are interdependent and cannot be achieved independently.
- iii) Edge and cloud intelligence collaboration must be robust to avoid conflict in requirements [4], [6].
- iv) Green AI is essential for managing and reducing the carbon footprint of AI-based 6G networks [3].
- v) Explainable and energy-aware AI is the foundation of governed autonomy, and it improves reliability and helps in regulatory compliance [7].

### 6.2 Mapping of Paper Sections to Representative Literature

| Key References                  | Section                                | Focus Area                                                             | Role of References in Section                                                                                           |
|---------------------------------|----------------------------------------|------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------|
| [1], [2], [7]                   | 2. Background & Related Work           | Evolution from 5G to 6G; architectural shift toward AI-native networks | Establishes the technological evolution and motivates the need for intelligence, autonomy, and architectural rethinking |
| [2], [3], [4], [8], [15], [18]  | 2.2 Core Principles of 6G Architecture | Privacy, energy efficiency, and autonomy as foundational pillars       | Identifies core architectural dimensions and contrasts 5G vs. 6G design philosophies                                    |
| [2], [6], [7], [11], [16], [17] | 2.3 Review of Existing Studies         | Fragmentation of current research                                      | Highlights gaps in existing literature and lack of integrated architectural approaches                                  |
| [2], [7], [8], [9], [10]        | 3. Research Methodology                | Qualitative literature synthesis and thematic analysis                 | Justifies survey-based methodology and use of cross-domain and regulatory perspectives                                  |
| [3], [7], [9], [12]             | 4. Centralized 6G AI Systems           | Limitations of centralized AI architectures                            | Demonstrates privacy, security, and scalability risks of centralized intelligence                                       |
| [1], [2], [6], [12], [15], [18] | 4.1 Privacy Challenges                 | Data aggregation risks; federated and edge intelligence                | Supports the transition toward privacy-preserving and decentralized AI mechanisms                                       |

| Key References                     | Section                                | Focus Area                                          | Role of References in Section                                                   |
|------------------------------------|----------------------------------------|-----------------------------------------------------|---------------------------------------------------------------------------------|
| [3], [4], [14], [15]               | 4.2 Energy Efficiency & Sustainability | AI energy footprint and Green AI strategies         | Provides evidence for energy-aware AI and sustainability-driven design          |
| [5], [7], [13]                     | 4.3 Autonomy & Intelligent Control     | Self-optimizing networks and governance issues      | Balances benefits of autonomy with risks related to security and accountability |
| [2], [3], [6], [7], [15]           | 5. Challenges & Limitations            | Trade-offs among privacy, energy, and autonomy      | Synthesizes interdependencies and motivates unified architectural optimization  |
| [1], [3], [4], [6], [7], [8], [14] | 6. Findings & Observations             | System-level insights from literature synthesis     | Consolidates survey findings into actionable architectural observations         |
| [3], [7], [8], [10], [12], [15]    | 7. Future Research Directions          | Trust, energy-aware learning, governance frameworks | Identifies open research challenges and directions for 6G standardization       |

### 6.3. Future Research Directions

Future research should focus on:

- AI-driven trust and risk scoring mechanisms for autonomous networks [8], [12];
- Green AI - Adaptive energy-aware learning frameworks that dynamically balance performance and sustainability [3], [15];
- Standardized governance and control frameworks for explainable and accountable 6G autonomy [7], [10].

## 7. CONCLUSION

As highlighted in this study and supported by WEF (2022) and Tran *et al.* (2024), the success of 6G will depend on a cohesive framework that jointly integrates privacy, energy efficiency, and autonomous intelligence.

- The study demonstrates that implementing a unified architecture, which balances Privacy, Energy Efficiency and Autonomy, is critical for the successful deployment of 6G networks.
- AI-driven automation and intelligence are crucial for achieving 6G performance, but without proper oversight, their deployment can create serious risks.

- By incorporating energy-efficient designs, responsible autonomous control, and privacy-preserving mechanisms, 6G has the potential to become a reliable, scalable, and sustainable communication platform.

Moving forward, it is crucial to prioritize this balanced approach in research and standardization to secure lasting benefits for society and the environment.

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